

Procedural Medical Training in VR in a Smart Virtual University Hospital

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Abstract. A smart virtual university hospital representing a real life one can prepare students for direct patient contact and provide possibilities for clinical practice. Such a virtual hospital will support student learning by providing adaptive and flexible solutions for practicing a variety of clinical situations at the students' own pace. This paper builds on a previous research on the Smart Virtual University concepts and explores the possibilities for medical procedural training with Virtual Reality. Two cases have been implemented for the pre-operative preparation training: neurological (brain tumor removal) and gynecological (ectopic pregnancy). The procedural training has been enhanced with the possibility to interact with real world medical data (MRI and ultrasound). The neuro case was tested on two occasions. The feedbacks from the tests have been generally positive, both in terms of general user experience and expected learning outcomes. The paper presents the implementation procedure, evaluation results and outlines the directions for future work.

Keywords: Smart Virtual University Hospital, medical procedural training, Virtual Reality

1 Introduction

A smart virtual university hospital mirroring a real life one can prepare students for direct patient contact and provide opportunities for clinical practice. We have worked with the long-term idea of establishing an online Virtual University Hospital (VUH) to create a holistic system and a venue for learning, research, and development [1]. The idea is to make a virtual mirror of the St. Olav's University Hospital (St. Olav), which is integrated with the faculty of Medicine at the Norwegian University of Science and

Technology (NTNU) in Trondheim, Norway. St. Olav is one of the most modern university hospitals in the world with a state of the art technological platform and modern clinical buildings.

Many studies reported the potential of 3D virtual worlds for educational activities [10]. With the advance of affordable Virtual Reality (VR) technology, such virtual environments can be used in combination with motion tracking and head-mounted displays (HMD) / VR goggles to increase the sense of immersion and improve the experience, making it more believable and transferable to the real life. VR goggles is a type of on-body VR devices that is worn on the head and has a display in front of the user's eyes [11, 12]. Most of these devices consist of a display and a tracking system. Examples include Oculus Rift (<http://www.oculusvr.com/>) and HTC Vive (<https://www.vive.com/>). Such devices are relatively affordable and suitable for educational context [13, 14]. E.g. Buñ et al. have experienced with low cost head mounted display accompanied by a haptic device to give procedural training to factory workers, like the specialist that operate glass moulding machines [20]. Hamrol et al. [14] and Moro et al. [26] have implemented and interactive virtual experience where students may learn about the body by seeing and manipulate it in a virtual world. Both researchs reports benefits for the learning outcomes of the students when using VR tools, as well as reporting that students are greatly enjoying the teaching experience.

In particular, 3D virtual environments have been widely used in the healthcare domain, including both desktop-based virtual worlds and other VR applications. Examples include training facilities for nurses and doctors [15-17], for example, in palliative care units [18], health information centers, and anatomy education [19, 20]. Such training is, on several occasions, reported to provide a cost-efficient and user-friendly alternative to real-life role-plays and training programs [18]. As demonstrated in several studies, "virtual worlds offer the potential of a new medical education pedagogy to enhance learning outcomes beyond that provided by more traditional online or face-to-face postgraduate professional development activities" [21].

VR simulators have been gradually more recognized as a valuable asset to improving the skills of surgeons [15] [16]. Traditionally, in surgical procedural training, more experienced surgeons have trained younger apprentices. By using VR simulations, the tutors can easier track the apprentices' progression, and assign targeted exercises for the apprentice to work with. Furthermore, the simulator can make the users perform uncommon scenarios that they will not be able to get sufficient experience from training on real world patients. Another feature gained by using simulators is exposing the user to stressful environments [17]. There have been multiple examples illustrating the usefulness of VR tools in medicine. At multiple hospitals in the United States, a simulator for training neurosurgeons called NeuroTouch neurosurgical simulator [18] have been implemented and tested. The simulator consist of two parts, NeuroTouch Plan and NeuroTouch Sim. The Neu-roTouch Plan consists of using Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) data to create 3D model of the a human head, with the ability to examine the brain for preparation of neurosurgery, e.g. removal of tumor. Once the tumor is located the users define the surgical corridor. Once the surgical corridor is defined, the user is moved to the NeuroTouch Sim part, where the users perform the surgery based on the planning performed in the first part.

Even though the surgeon simulators have come a long way in preparing surgery students for a multitude of different surgeries, they are still not as widely implemented as one would have believed them to be given their apparent success in literature. Stefanidis et al. argues that simulators today are complex to construct and implement, as well as expensive. He argues that cost effectiveness and a more effective development process is needed for simulators to achieve greater success [19]. There have been attempts to develop affordable surgical simulators using general purpose input devices. E.g. at Japitur College of Engineering in India, Mathur [21] have developed an surgeon trainer using Oculus Rift with the low cost input device Razer Hydra [22]. The users of the systems are using the headset to view the virtual world, and the controllers to interact with it from a stationary sitting position.

Adding medical data into medical simulators has a significant potential benefit for student learning. E.g. Rudolf et al. assessed the value of real world medical data in their VR application [50], concluding that although hard to implement, real world medical data could have immense benefit in a VR learning application. Another application for virtual interaction with medical data is the Dextroscope [29], made to support surgical evaluation and decision making. The system uses preoperative images in combination with segmentation of critical anatomic structures to present an information-fused 3D model on a stereographic display.

In this paper, we present the development of a low-cost solution for procedural training for room-scale Virtual Reality (Oculus Rift and HTC Vive) with integrated medical data for procedural pre-operative preparation training. Two cases have been identified in collaboration with the specialists: neurological (brain tumor removal) and gynecological (ectopic pregnancy). The cases have been implemented as a unit in the Smart University Hospital framework earlier described by the authors [1]. The rest of the paper is organized as follows: the following section outlines the implementation details and training scenarios. Section 3 presents the results of a preliminary evaluation with medical specialists of the neuro-scenario, while section 4 discusses the findings. Section 5 concludes the paper, outlining directions for future work.

2 Implementation and scenarios

2.1 Procedural training at the Smart Virtual University hospital: implementation

The procedural training unit was modelled in Unity3D, supporting a neurological and gynecological scenario, to be used with HTC Vive or Oculus Rift. The models for the hospital hallway, rooms and operating rooms were based on the original design of the VirSam project [1]. They were modelled by taking photographs of the operating hall at the Eastern Neurological centre at St.Olavs, in order to create a familiar environment for neurological surgeons.

The unit contains 3 operation rooms for different purposes. Operation room one for the gynecology case is used for an operational scenario where the surgical nurse hands over the surgeon the right equipment at the right time. Operation room two is used to

store proof of concept models that are either not relevant to the scenario or too cumbersome for non-technical personnel to use. Operation room three is used to perform the neurosurgery scenario. Moving from VirSam [1], it was key to improve the interaction the user has with the virtual world. In the VirSam scenario, when performing the ultrasound, the physician would look at a frozen screen and vocally declare the state of the ultrasound. In this case, two methods were implemented to create the mixed reality environment and allow working on real medical data. The first method was to create an ultrasound machine where the user could perform ultrasound on a patient. When the user moved the probe, the image on the ultrasound machine would update accordingly. The second method was to load and render raw medical data processed through the Volume Viewer Unity asset purchased.

The ultrasound machine works by mapping positions of the ultrasound (US) probe in the application to real ultrasound images. The ultrasound images are frames extracted from an ultrasound examination video. The medical data was also used to create a navigation system, used in the neurology scenario (Fig. 1,2). The users use the navigation system by holding the ‘MR-Wand’ in the patients head. The MRI on the ACS panel will update based on the MR-Wand’s position relative the patient’s head. It tracks in three dimensions, making it possible to locate where the tumor is, in addition to the depth of the tumor

Giving users the ability to communicate was an important functionality to implement, as interprofessional communication and collaboration was the original focus of VUH/VirSam. Currently, it is possible to connect players using Oculus Rift, HTC Vive and desktop together in the same instance of the application. While the users with VR devices will be represented as a head with hands, the desktop player will have a full-bodied avatar. Users on a desktop will be able to move around and observe all interactions taking place, but will not be able to interact with objects. This way, the desktop users are considered observers while the VR users are considered actors.

In order to ease the development and ensure the quality of educational applications, it is important to have a clear understanding of the high level goals. Scenarios were implemented to address these goals. The gynecology scenario implemented is based on for the earlier iteration of the VUH [1], while the second one was a neurology scenario developed with feedback from the department of neurology at St.Olavs hospital. Both scenarios are providing the learners with pre surgery tasks, but with a different focus.

2.2 Neurology scenario

In the neurology scenario, the users are playing out some of the first steps performed during neurosurgical removal of a brain tumor. The scenario is split into three tasks:

- 1. Pre-operative planning.** The students are expected to use a panel consisting of the axial, coronal and sagittal (ACS) view of MRI from a patient to locate the tumor and mark the middle of it (target). When the user have marked the patient, they click the solution button to compare with the correct solution.

- 2. Patient positioning, shaving and marking the entry point of the craniotomy.** The patient is to be positioned correctly on the surgical bed, and the head of the patient needs to be correctly rotated to ensure proper access to the tumor and optimal conditions

for ultrasound acquisition. When the patient is laid correctly, the patient needs to be shaved in order to get access to the point of operation. When the patient is shaved, the user marks the point of surgical entry. After marking the point of entry, the user clicks on the solution button to get the correct setup (Fig. 1).

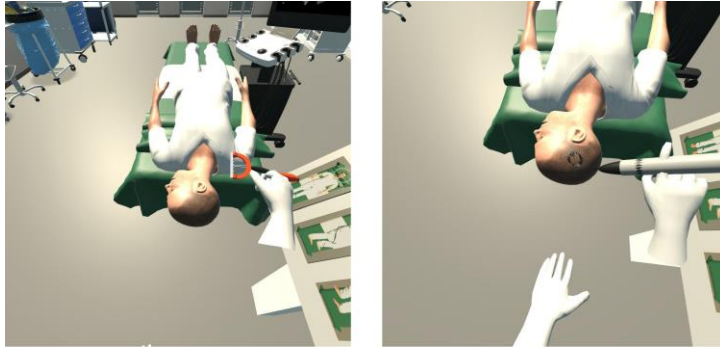


Figure 1: Examples of how to shave and mark the patient

3. Navigation and ultrasound acquisition. When the patient is positioned correctly, the next task is to verify the position of the tumor. This is done in two steps. The first step is verification by use of the navigation system. To use the navigation system, the user has to pick up the MR-Wand, the white wand with a blue tip, and place it over the patients head. The ACS panel above the operation table updates based on where the pen is located on the head. It tracks in three dimensions, meaning that it is possible to point the marker inside the head to determine how deep inside the head the tumor is located. The ACS panels shows that the tumor is in the centre (Fig. 2).

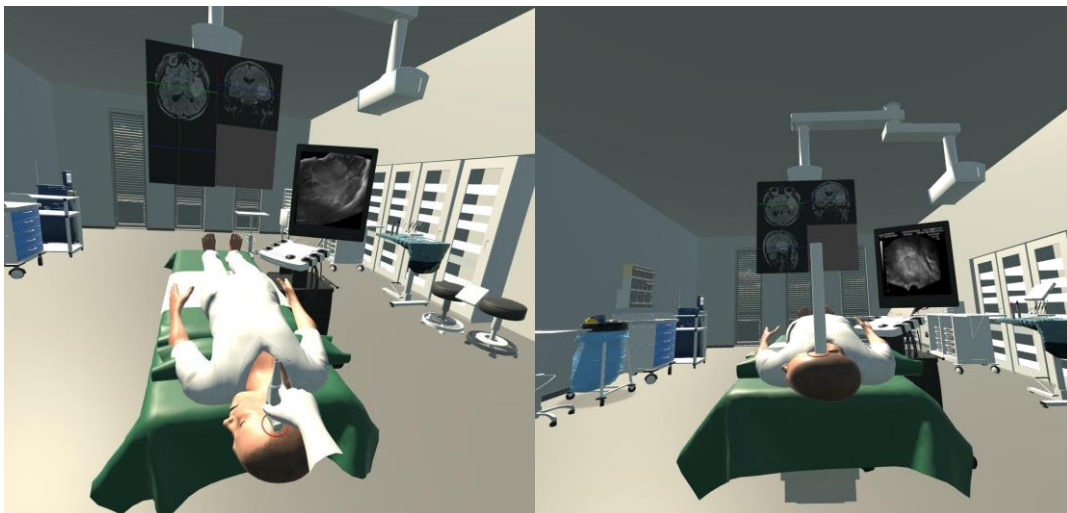


Figure 2: Use of navigation system and ultrasound

The second step is verification by ultrasound. In neurosurgery, it is not sufficient to only rely on the MRI when performing an operation. Firstly, the MRI are not completely accurate. The inaccuracy of the scans can close to a centimeter. In addition, once the operation has started, the brain might move around, making the tumor move as well. To remedy these issues, ultrasound is used complementary to the MRI during operation. Ultrasound scans are performed in intervals to determine the position of the tumor and critical brain tissue. These scans are compared with each other throughout the surgery. In the last task, the user has to perform the first ultrasound scan. To perform the scan, the user picks up the ultrasound probe and move it to the point of entry on the head. If the tumor is observed at the assumed location the user has completed the scenario (Fig. 2).

2.3 Gynecology scenario

The gynecology scenario focuses on performing abdominal ultrasound and interaction between members in a medical team and with patients. It is divided into three tasks.

1: Meet and talk with the patient. In the beginning of the scenario, the nurse enters the room where the patient and her husband is waiting. The patient is not feeling well, and is clutching her stomach in pain. The husband is visibly in distress and looks up to the nurse for confirmation, and to simulate a sensation of real.

2: Perform ultrasound. The goal of this tasks is to locate and identify the abnormalities in the patient's uterus. The user needs to guide the patient from the patient's room to the ultrasound room, and then perform the ultrasound examination. The users should be able to detect abnormalities in the ultrasound, in order to conclude that surgery is required. The user picks up the up the ultrasound probe by holding a hand over the probe and press the grip button. The controller hovering over the probe will turn yellow (Fig. 3). When the probe reaches the silhouette on the patient's abdomen, the ultrasound machine begins transmitting images to the television screen behind the bed while the user will feel a haptic feedback (vibration) from the VR controllers. The user should be able to identify the rings in the ultrasound images, indicating extra uterine/ec-topic pregnancy, and the patient needs to be taken to the operating room and be prepared for surgery.

3: Preparing for surgery. The user prepares the patient for surgery by explaining the diagnosis, and guides the patient to the operation room. Further, the surgical team goes through the safe surgery checklist.

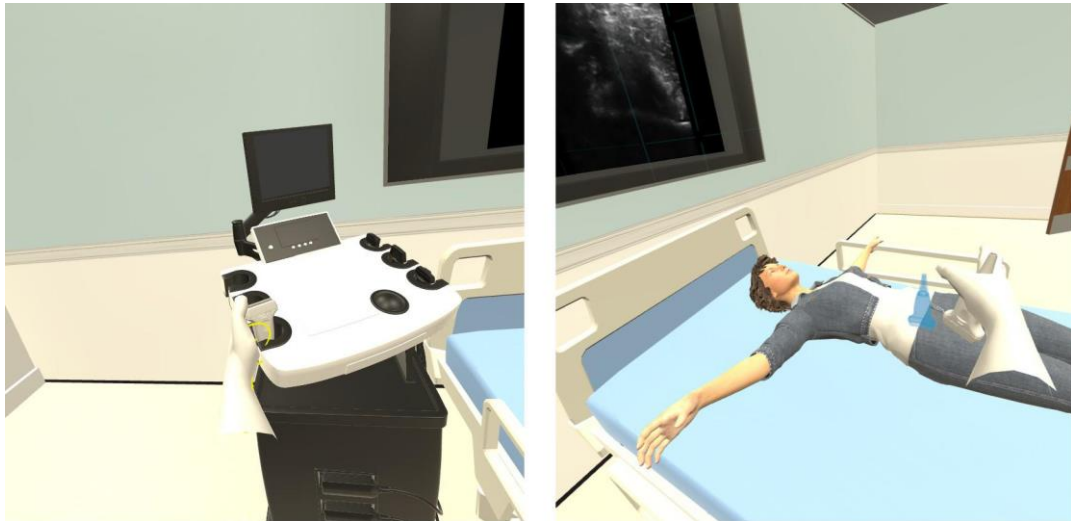


Figure 3: Performing ultrasound examination in the gynecology scenario: Picking up ultrasound probe and observing the data

3 Evaluation

3.1 MedSim conference

During the 2017 Network Conference, held at the Medical Simulation Centre at St. Olavs hospital, the project team presented the project to volunteering participants on a stand. With instructions from the developers, the participants got to go through the core parts of the system to try out the functionality. The neuro scenario was mostly implemented, but not yet robust enough to leave the testers on their own. At the end of the test, participants were asked to fill out a short survey asking core questions about the functionality and their experience in the virtual world.

Setup and execution. This test was conducted using one VR headset Oculus Rift, as well as one laptop for testing the network functionality. The original plan was to get two users using VR and two users using laptops, but due to technical difficulties, most players got to test with one VR only. Before and during the tests, the participants were carefully instructed by one of the developers. The tests usually lasted between 5-15 minutes per person

The test subjects. The individuals participating in this tests were 12 technical and medical experts from different parts of Norway, interested in simulation in medical practice.

Findings. After a participant had tested the system, he or she would be asked to fill out a survey constructed by the developers. The participants were also encouraged to give feedback in free form. The results are shown in Figure 4. All questions were posed in a manner that should be answered on a Likert scale from 1, strongly disagree, to 5 strongly agree.

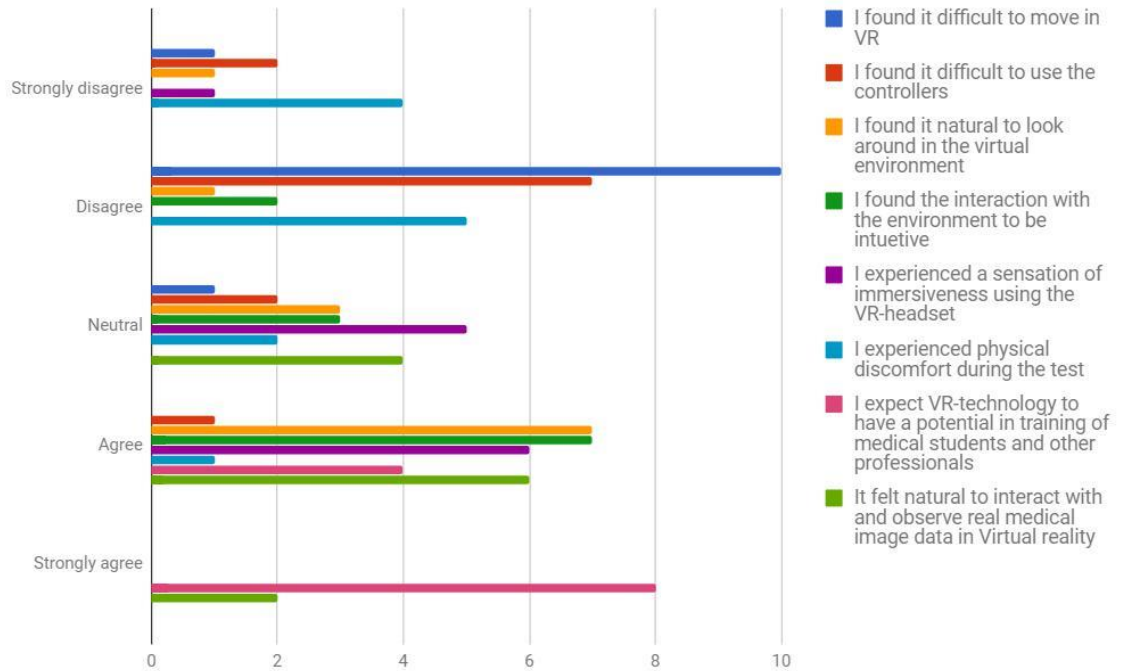


Figure 4: Chart created based on feedback from MedSim

3.2 Neurosurgeon seminar

In June of 2017, the application presented in this paper was demonstrated at the 9th annual course in ultrasound in Neurosurgery. The application was used as one of four stations on which the participants should explore the simulation possibilities and get a first hand experience with different equipment and concepts regarding ultrasound in neurosurgery. The focus on this test was shifted somewhat from what was already established in earlier user tests. Instead of focusing on whether the users are able to interact with the VR gear and the virtual environment, observations were made on how the users interacted with the medical equipment and the medical data.

Setup and execution. Oculus Rift was used as the VR HMD in this presentation. Moving from earlier experiences, it was decided to make use of three base stations, rather than two. This led to a less disruptive experience for the testers, as they will no longer get disconnected from the application if they are rotated away from them.

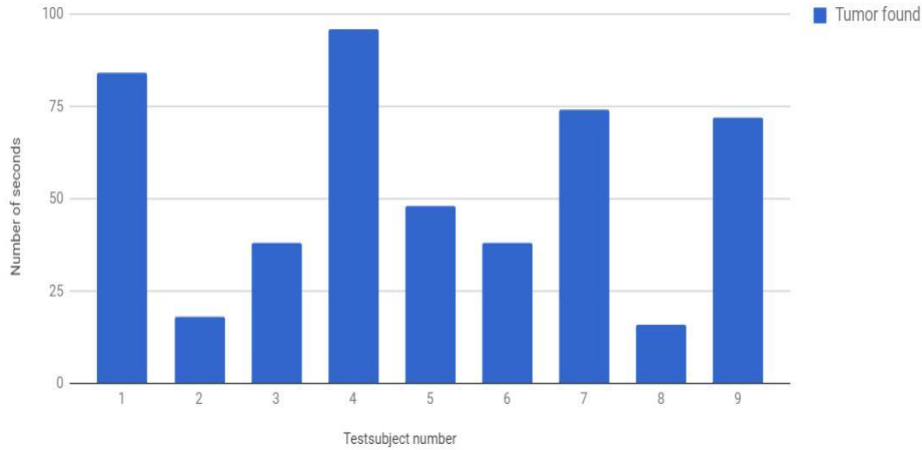
The execution was a three step process for each test subject. Firstly, in order to give the testers an overview of the application and make them ready for the tasks they were supposed to execute, a quick walk through was given by a team member. Secondly, they were given a quick introduction to the controller and the different buttons they needed to use in order to manipulate the virtual world. Lastly, they were given the headset and guided through the scenario.

Test subjects. The test subjects in this execution was mainly surgeons in training or surgeons who wanted to expand their knowledge in ultrasound guided neurosurgery. The age of the participant ranged from late twenties to sixties. None of the testers have used a VR HMD prior to the tests.

Findings. The data gathered in this test was made by observation, post test talks and a video recording of all subjects in the application, with the focus on the following aspects:

- 1) How quickly the testers became familiar with the environment (number of seconds from start of test until first teleport and until the case was chosen.
- 2) How quickly the testers were able to locate the tumor in the ACS-panel; (number of seconds between first attempt to interact with the panel and until the tumor was marked correctly)
- 3) How well they were able to lay the patient and marking him correctly (how close to the correct solution the tester managed to position and mark the patient)
- 4) How well they were able to interact with the medical data using the MR-Wand and ultrasound probe. (I.e. whether the tester manage to locate the tumor with the MR wand and ultrasound probe)

The average time users spent before choosing the case was 1:24 minute, with a standard deviation of 38 seconds. Placing the patients correctly proved mostly to be successful. Only two out of the nine participants had crucial errors in their placements or markings. The rest of the participants had the patient mostly correctly placed. All those who got the time to test the MR wand and ultrasound were able to use those tools and recognize the tumor. The time required to find the tumor is presented in Fig. 5

Figure 5: Number of seconds taken to find tumor in the ASC panel

4 Discussion

The application presenting the neurosurgical scenario and extended functionality was tested on two occasions, both during and after the development was finished. The feedback gathered presents interesting findings related to the usefulness of the application, especially in an educational context.

Interactivity. The fact that users need some time to become familiar with the VR gear is to be expected. For complete novices in VR, problems with understanding how to aim the teleport beam and what button to click are problems developers need to account for. In order to make new users familiar with the unusual interface, ‘virtual hands’ were implemented and programmed to animate in a manner that simulated the physical movement of the fingers. As shown in the test performed at MedSim, there was largely a consensus that the interaction with the controllers were not difficult. During earlier tests, some users had trouble finding out which items were possible to interact with and which button they had to press to interact with it. Therefore, in the design the interactable items have been separated from non interactable ones by shape and color.

VR-sickness. A recurring concern with VR applications have been VR-Sickness, which may leave users unable to use applications for a prolonged period of time. In this project, numerous design decisions have been adopted to minimize the sensation of nausea and strain on the users. The most important aspect here is the continuous focus on performance, since as John Carmack [43] argues, poor performance could lead to latency and screen flickering, as well as the implementation of teleport functionality, which removes the all discrepancy between the user’s physical and virtual movement. The result can be seen in the MedSim result section, where only one participant reported discomfort during the test (Fig. 4).

Using real medical data. From the literature, the use of real world medical data is perceived as having a significant potential in educational applications, but difficult to implement [50]. The prototype evaluation results show that it is indeed possible to utilize real world medical data to support a learning application. One tester announced on the surgical seminar that the navigation system and the ultrasound implementations made it feel like he was working on a real patient. The user did not look at the patient when performing the navigation, instead he was only looking at the screen. Being able to interact with models and imagery of the human body in a fully immersive virtual environment enables exploration of the data in a new way. Utilizing medical imagery to recreate apparatus and scenes that are known and familiar to the user will help users perform training on well-known procedures, as well as developing new training scenarios focusing on advanced interaction, interpretation and 3D visualization of medical data.

Proper use and interpretation of MRI and ultrasound images is a field of study in itself. Therefore, it was paramount that the interaction with the medical data was as similar to the real world interaction as possible, or manipulated in a way as intuitive as possible. From the user tests, we can see that the average tester spent an average of just under a minute to properly locate the tumor in the ACS-Panels. Having the ability to use finger pointing and the sliders, the ACS-Panels was made to simulate desktop computer and touch screens on the laboratory equipment used in surgery respectively, enabling the testers to interact with the equipment in a way that was familiar to them. Interaction with the MR-Wand and the ultrasound probe was mostly a success. Some needed assistance on how to use one, or both, but most understood they were supposed to use the VR gear as they would do in real life. The main issue with the ultrasound probe was the inability to rotate the probe and get a proper rotated view, but most testers did not notice this flaw.

Collaborative learning. With the implementation of cross-platform utilities, there are multiple ways to play out the neurology scenario, connecting to a session using either VR equipment or using the desktop version. One way is a student walking through the scenario using VR equipment while a teacher is present in the room from a desktop version, able to offer advice and feedbacks. Another way is a teacher executing the case with students observing. At the moment, two VR users are able to communicate and interact with each other in the virtual world, passing items with each other, like the ultrasound probe or the marker, and all actions they perform in the VW will be observed by the other actors. This opens for additional learning scenarios, e.g. that simulates nurse-surgeon communication before, during and after a surgery.

Further development of Smart Virtual University Hospital. The goal of this project was to develop a medical learning application for procedural training within the Smart Virtual University Hospital framework. Compared to the previous implementations of Virsam/VUH [1], the user was able to move freely in the virtual environment, interact with equipment using physical movements and access medical data. The evaluation results indicated that the realism of the movement and the environment contributed to increased immersion, made it more user-friendly and resulted in reduced time needed to be proficient in the application. The development of high-quality realistic scenarios is essential for efficient training. We are currently working on a methodology

for efficient development of new training scenarios in VR based on medical cases. Apart from realism and interactivity, it is critical that the users know at all times what actions need to be performed in order to proceed to the next task, providing users with continuous feedbacks. Also, it is important to combine procedural training scenarios with communication and collaboration training aspects that are an important part of the Virtual University Hospital. Another challenge is integration of different technological platforms and solutions we have been using as a part of VUH into a coherent whole.

5 Conclusions and future work

In this paper, we have discussed developing a virtual university hospital environment designed for procedural training in VR. The initial setup and introduction to VR might be time consuming. However, with a well-designed user interface, and with careful guidance, it is achievable to have novice users interact with the virtual world with some degree of proficiency after minutes. The design of educational applications is a complex task, and one way to solve this is to design such an application after a set of tasks that each bring educational value, preferably in collaboration with an expert. This is why the application in this project have been centered around scenarios with a clear structure and learning goals.

Integrating real world medical data further increased the sense of immersion the user felt when playing the scenario and gave them an exciting new way to interact with MRI and ultrasound images. In this project, we have shown that users should interact with the data in a way that closely resembles the actual usage in the real world for the experience to have an educational value. In this project, a scenario where users were forced to use their knowledge of MRI and ultrasound in order to complete a given task properly through experimentation and analysis with the data was implemented. Construction of these types of scenarios needs to be done in collaboration with experts in the given field.

It is possible to practice collaboration and communication skills by adding a networking layer. However, the networking capabilities were not properly tested in this project. Time constraints on the user tests, in addition to the limited amount of testing areas and gear needed made it difficult. The users that got to experience duo-user play through of the neurology scenario at MedSim provided positive feedbacks.

Based on experimentation and exploration in this project, multiple directions for future work have been identified:

Medical data. The testers suggested that further integration of medical data in the application is desirable, with two possible improvements. The first one is the ability to slice the data at a random angle and offset, simulating the use of an ultrasound probe in the real world. Another way of interacting with the data that was suggested in tests with surgeons, is the ability to view the navigation markers position on the ACS-Panel that is positioned above the bed. Such functionality will immerse the user further as well as opening for more complex scenarios.

AI. In order for a training scenario to be easily accessible, a replacement of human participants in the scenarios with artificial intelligence agents could be an option. In order for an AI to simulate conscious decisions, it should respond to voice commands or keywords. There already exists tools making this possible, but there is an overhead setting them up, and in their current state, they are only usable in English. Unity3D ships itself with a voice recognition tool that is quite simple to set up and get working. The problem with this software is the quality of the recognition, especially when considering any recognition of more than a few commands. In its current state, human simulation and speech recognition still pose significant challenges, though given the scripted nature of the scenarios, it is possible to hard-code behavior and responses to simulate a conscious decision.

Improved feedback system. Today, the application provides an expert-set solution for the scenarios, and the user may assess his or her success in the scenario based on the solution. During development, the team came up with different ideas for more complex feedback systems, some sort of numerical feedback that in a meaningful way grades the performance of the user. A score system could be visible after the user is done setting up the patient, and could be showed in VR or outside, with pass or fail values, giving the users further feedback on what is expected of them.

An example of a possible feedback is if the user marks the entry at a point in the brain containing a significant amount of critical nerves, he should be informed about why using this point would represent a danger for the patient. Personalized and adaptive feedback based on different metrics like the placement of the torus or the angle of the neck of the patient would be most useful for the learner.

Further development of a Smart University Hospital framework. The procedural training unit described in this paper will be a part of the overall Smart Virtual University Hospital Framework. Several new cases, both collaborative and non-collaborative, with the focus on communication and procedural skills will be developed, allowing users to choose a training scenario based on the study program and the preferred choice of equipment. The facilities in the Virtual University Hospitals will be available in Unity or Second Life environment, with VR glasses (Oculus Rift or HTC Vive) in a VR lab, with desktop computer or later with mobile devices.

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